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# Binary stars in globular clusters: detection of a binary sequence in NGC 2808?†

F.R. Ferraro<sup>1</sup>, E. Carretta<sup>1</sup>, F. Fusi Pecci<sup>1,2</sup>, A. Zamboni<sup>1</sup>

(1) Osservatorio Astronomico di Bologna, Via Zamboni 33, 40126 Bologna, Italy

(2) Stazione Astronomica di Cagliari, I-09012 Capoterra, Italy

†Based on observations obtained at the European Southern Observatory, La Silla, Chile

**Abstract.** A CCD  $V, V - I$  colour-magnitude diagram (CMD) of the Galactic globular cluster NGC 2808 has been obtained with the ESO-NTT, reaching down to  $V \sim 24$ .

The highly populated Main Sequence (MS) presents a significant broadening redward to the MS ridge line, larger than expected from photometric errors alone, which could be interpreted as due to binary candidates.

**Key words:** Cluster: globular: NGC 2808, Techniques: photometry, stars: Population II, binaries: general

## 1. Introduction

There are various (direct and indirect, but always difficult) approaches followed so far to detect binaries in Galactic Globular Clusters (GGCs) (see Hut et al. 1992 and Bailyn 1995 for a discussion). Most of them have been unsuccessful, but this may well be due to the fact that the surviving binaries are likely segregated in the inner cluster regions, hardly observable from the ground because of crowding.

One possible path to explore consists in the study of the intrinsic width of the Main Sequence (MS), looking for some sort of “parallel” sequence due to the photometric combination of the binary components (see Romani and Weimberg 1991). This approach requires the achievement of a very accurate photometry (to  $\sim 0.01 - 0.02$  mag) for a very wide sample of faint MS stars. On the other hand, other methods imply time-consuming and distance-constrained spectroscopic observations, usually sensitive only to the brighter objects with present day instrumentation.

The true fraction and the physical nature of binary stars in a GGC is a clue element that brings information on a variety of topics like the environment in which the

cluster was born, the details of the star formation, and the subsequent internal dynamical evolution. While theoretical models are presently only poorly constrained by any observational (and quantitative) data-set, it is now well established that a strict connection does exist between stellar and dynamical evolution of a GC star, as revealed for instance by the morphology of the evolved branches, in particular the Horizontal Branch (HB; see e.g. Fusi Pecci et al. 1993 for discussion and references).

NGC 2808 ( $\alpha_{1950} = 9^h10.9^m$ ,  $\delta_{1950} = -64^\circ39'$ ) is one of the most interesting objects to study, in this respect, since its very high concentration is likely to enhance any effect due to the dynamical evolution of binary or multiple star systems. This cluster is also the typical template of a growing class of GGCs with a net, bimodal HB morphology (see Harris 1975, Ferraro et al. 1990-F90, and Rood et al. 1993). This, in turn, could well be heavily affected by the evolution of binary systems that at later stages can populate both the red and the blue HB extremes (Fusi Pecci et al. 1993). Further, to explain its bimodal HB, van den Bergh (1997) has recently suggested that this cluster might have formed by mergers (but see Catelan 1997). Any new (though preliminary) information can thus be useful to have a deeper insight on its properties.

In this research note we present a very preliminary evidence of a secondary sequence running parallel to the MS of this cluster that, if confirmed, could be interpreted as composed of unresolved, candidate binary systems.

## 2. Observations and data reduction

A set of deep  $V$  and  $I$  frames (3 exposures of 600 secs in each filter) were acquired under good seeing conditions (0.7-0.9" FWHM) on January 1995 at the NTT telescope (ESO, La Silla, Chile) with the EMMI camera equipped with a  $2048 \times 2048$  CCD detector. The image scale is 0.25 arcsec/pixel, yielding a total field of view of  $8.5' \times 8.5'$ . In order to avoid severe crowding conditions, the results reported here are based only on a sub-field of about  $4' \times$

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Send offprint requests to: ferraro@astbo3.bo.astro.it

4', whose center lies about 6' southward and 2' eastward away from the cluster center (see Figure 1).

All reductions were performed using the package ROMAFOT (Buonanno et al. 1983). Details of the image analysis are very similar to those described elsewhere (see F90, Ferraro et al. 1992) and will not be repeated here. The data-files are available upon request.

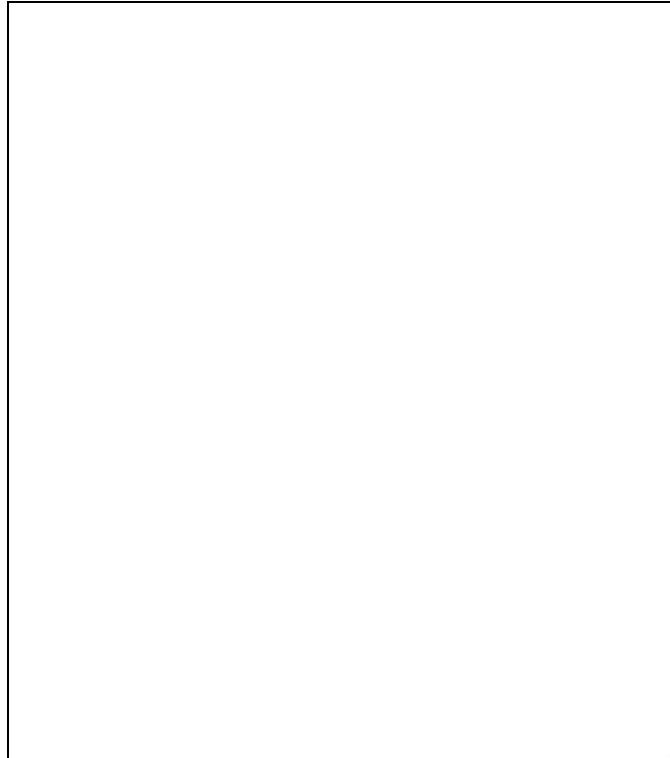
The instrumental magnitudes (from profile-fitting) were first tied to fixed aperture photometry and then referred to the photometric Johnson system using 15 stars in the Landolt (1992) standard fields Rubin 149 and SA98. The resulting calibration equations are:

$$V = v + 0.024(v - i) + 23.793$$

$$I = i - 0.077(v - i) + 23.260$$

where  $V$ ,  $I$  are standard magnitudes and  $v$ ,  $i$  indicate the instrumental ones. Atmospheric extinction was taken into account by means of average extinction curves appropriate for La Silla.

Based on comparison of 70 stars in common, we note here that our new calibration is fainter (0.12 mag) in  $V$  than previously obtained by F90; no comparison was feasible in the  $I$  band.

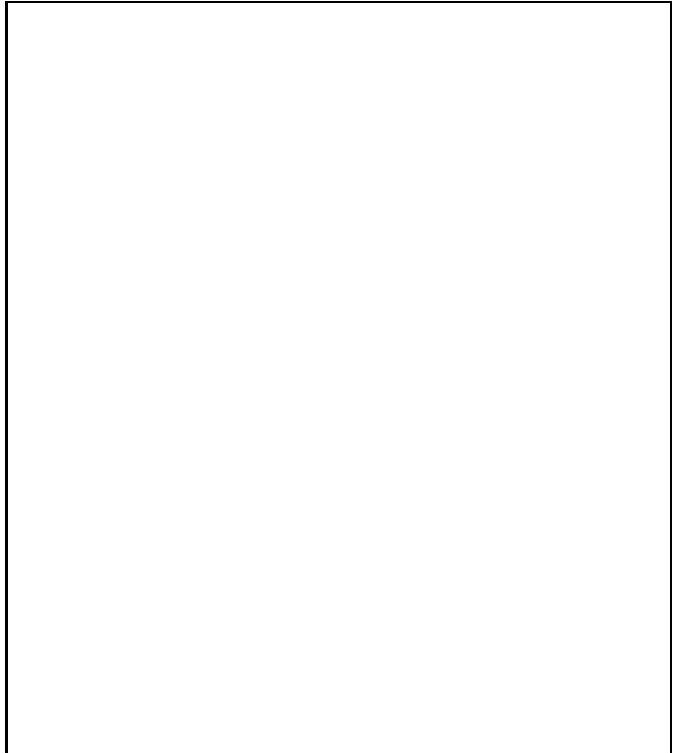


**Fig. 1.** The map of NGC 2808 with the location of the sub-frame of about 4'  $\times$  4' analyzed in this note.

### 3. Results

Figure 2 shows the ( $V$ ,  $V - I$ ) CMD for 3174 stars detected in the selected sub-frame. Both the turn-off (TO) region and MS are well defined. However, *the most intriguing evidence is the presence of a clear broadening above and to the red of the MS, which can be interpreted as a secondary sequence, running parallel to the MS, but at brighter magnitudes and redder colour.*

In Figure 2, to make more evident this feature, we marked the claimed parallel sequence with a dashed line. The distance in magnitude of this “secondary” sequence from the MS is somewhat less than 0.75 mag. Note that equal component binaries would lie at the same colour and 0.75 mag brighter than the two individual members (Romanini and Weinberg 1991), and this magnitude difference should thus be considered as an upper limit. Consequently, taking also into account the photometric errors, the average difference here measured for the two parallel sequences is substantially compatible with the above limits.



**Fig. 2.**  $V, V - I$  CMD of NGC 2808; errorbars for the photometry are plotted on the left. Mean ridge lines for the MS (solid line) and the candidate binary sequence (dashed line) are overimposed to the data.

To test the existence of the candidate binary sequence we have considered various luminosity bins along the MS (between 21 and 22.5, see Table 1). Then for all the stars in each bin we derived the distribution of the distances

$(\delta x)$  from the MS ridge line (MSRL). The observable  $(\delta x)$  is defined as the geometrical distance in the  $(V, V - I)$ -plane of each star from the adopted MSRL, with  $\delta x > 0$  or  $\delta x < 0$  if the star is redder or bluer than the MSRL, respectively.

In Figure 3, the distributions of the  $(\delta x)$ -values in the ranges  $V = 21.5 \div 22.0$  and  $V = 21.0 \div 22.0$  are shown for illustration and clarity.

**Table 1.** K-S test at different Magnitude ranges considered along the MS

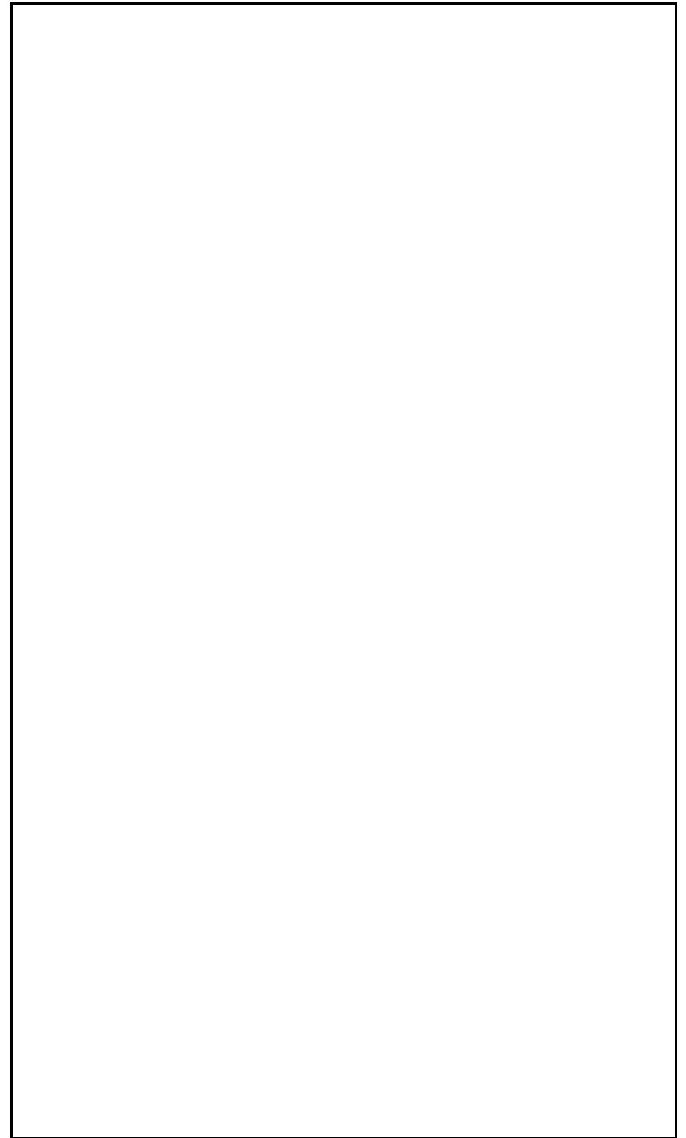
Section	Mag. range	K-S
A	21.0–22.0	0.7%
B	21.5–22.0	0.5%
C	21.5–22.5	3.0%

As can easily be seen, both panels in Figure 3 show that the distributions of the  $(\delta x)$ -values are clearly asymmetric. In fact, besides the main peak centered on the MS, there is a quite evident secondary peak, displaced by about  $\delta x = 0.12$  from the main one. In our view, this is a direct evidence for the presence of a secondary sequence along the MS as the asymmetric shape itself of these distributions is a proof that the broadening of the MS is not just due to photometric errors.

Before discussing at any level the possible origin of the stars located in the parallel sequence, we have tested the statistical significance of this claimed feature. To this aim we have compared the number of stars distributed over equal intervals in distance ( $|\delta x|$ ) from the MSRL lying in the blue and red side of the distributions.

Over the magnitude interval  $21.5 < V < 22.0$  (where the effect is best evident), the number of stars within  $|\delta x| < 0.1$  from the MSRL is almost the same (within  $1\sigma$ ) on both side of the distribution (138 stars on the blue side and 159 on the red one, respectively). On the contrary, if one consider the range  $0.1 < |\delta x| < 0.2$ , one finds only 15 stars bluer than the MSRL to be compared with 48 objects located on the red side. Hence, the number of red stars is more than 3 times that found in the blue side of the distribution.

Moreover, a Kolmogorov-Smirnov (KS) test applied to evaluate the significance of the detected difference in the red and blue distributions yields a very low probability that the two distributions have been extracted from the same *parent* distribution. In fact, as can be seen in the last column of Table 1 for the 3 intervals of magnitudes between  $V = 21.0$  and  $V = 22.5$ , the probability that the



**Fig. 3.** Histograms of the distances of stars from the MS mean ridge line in NGC 2808 (dots); negative values refer to stars bluer than the ridge line. Gaussian fits are overimposed to the data. Panel (a): bin from  $V = 21.5$  to  $V = 22.0$ , panel (b): bin from  $V = 21.0$  to  $V = 22.0$ .

presence of the secondary peak is not due to a statistical fluctuation ranges from  $\sim 97\%$  ( $2.2\sigma$ ) to  $\sim 99.5\%$  ( $2.8\sigma$ ).

The  $(V, V - I)$ -CMD shown in Figure 2 and the statistical tests carried out above indicate thus that several stars in the MS of NGC 2808 lie on a secondary sequence running parallel and redward to the MS. From the areas of the interpolating Gaussian fits (see Figure 3) we can also obtain a (rough) estimate of the percentage of stars populating the two sequences over the total number of MS stars. In the different magnitude bins considered above we obtain for the parallel sequences figures ranging from 20.0 to 28.0 %, with a mean values of  $\sim (24 \pm 4)\%$ .

#### 4. Optical and/or physical binaries?

Concerning the possible nature of the stars populating the parallel sequence, the label *unresolved binary* has to be taken with particular caution as it may mean either unresolved *optical* binaries or unresolved *physical* binaries. In fact, since we are making photometric measurements in a very crowded field, it has to be seen as quite normal the detection of some blended images.

On the other hand, the fraction of candidate binaries we have found ( $\sim 24\%$ ) is somewhat too high compared to the number of unresolved blends one can predict to find (just because of crowding) "making artificial star" experiments (which would yield here values close to  $\sim 10\%$ ). As a consequence, one could also conclude as a working hypothesis that a non negligible fraction of the stars located on the parallel MS could represent reliable intrinsic binary candidates.

Obviously, since stellar crowding mimics the effect of the physical dynamical relaxation acting in the cluster and concentrates the optical blends toward the cluster center, as does mass segregation with true (and more massive) binary systems, it is too early to extend deeply the discussion of the possible implications of this observational result, if confirmed. However, it may be interesting to recall that NGC 2808 presents one of the most intriguing HB-morphologies found in a Galactic globular cluster so far. As reported in the Introduction, since the early observations carried out by Harris (1974, 1975), it was evident that the HB of NGC 2808 is highly bimodal. Moreover, the latest HST data presented by Djorgovski et al. (1996) have shown that, besides the already detected bimodality, the blue HB of NGC 2808 is actually made by 3 sub-portions, separated by quite evident gaps.

Within this framework still so uncertain and worth of further exploration, the detection of a fraction of *physical* binaries could open new perspectives to the possible interpretation of the detected peculiarities in the HB morphology. For instance, one could imagine that at least a group of the HB stars could represent the descendants of the binary systems. The discussion of how this could occur is however beyond the purposes of the present work, and we refer to the review papers by Hut et al. (1992) and Bailyn (1995) for further analysis of this aspect.

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#### References

- Bailyn, C.D. 1995, ARA&A, 33, 133  
 Buonanno, R., Corsi, C.E., Fusi Pecci, F. 1985, A&A, 145, 97  
 Buonanno, R., Buscema, G., Corsi, C.E., Ferraro, I., Iannicola, G. 1983, A&A, 126, 278  
 Crocker, D.A., Rood, R.T., O'Connell, R.W. 1988, ApJ, 332, 236  
 Djorgovski, S.G. et al. 1996, in *Stellar Ecology Workshop*, ed. R.T. Rood (Cambridge: CUP)  
 Ferraro, F.R., Clementini, G., Fusi Pecci, F., Buonanno, R. 1992, MNRAS, 252, 357  
 Ferraro, F.R., Clementini, G., Fusi Pecci, F., Buonanno, R., Alcaino, G. 1990, A&ASS, 84, 59 (F90)  
 Fusi Pecci, F., Ferraro, F.R., Bellazzini, M., Djorgovski, S., Piotto, G., Buonanno, R. 1993, AJ, 105, 1145  
 Harris, W.E. 1975, ApJS, 29, 397  
 Harris, W.E. 1974, ApJ, 192, L14  
 Hut, P., McMillan, S., Goodman, J., Mateo, M., Phinney, E.S., Pryor, C., Richer, H.B., Verbunt, F., Weinberg, M. 1992, PASP, 104, 981  
 Landolt, A.U. 1992, AJ, 104, 340  
 Leonard, P.J.T., Fahlman, G.G. 1991, AJ, 102, 994  
 Romani, R.W., Weinberg, M.D. 1991, ApJ, 372, 487  
 Rood, R.T., Crocker, D.A., Fusi Pecci, F., Ferraro, F.R., Clementini, G., Buonanno, R. 1993, in *The Globular Cluster-Galaxy Connection*, A.S.P. Conf. Ser., 48, 218, eds. G.H. Smith and J.P. Brodie